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DESCRIPTION

HOT WORK TOOL STEEL AND MOLD MEMBER EXCELLENT IN RESISTANCE TO MELTING LOSS

TECHNICAL FIELD

[0001] The present invention relates to a hot work tool steel that is excellent in resistance to melting loss and is suitable for use as a mold member for Al die-casting, and also relates to the mold member.

BACKGROUND ART

[0002] As a material of a base, a core, a core pin, and a molten-metal supply tube of an Al-die-casting mold (hereinafter, generally referred to as the "mold member(s)"), a hot work tool steel such as JIS SKD61, SKD6, or SKD62 has been used.

[0003] Meanwhile, Fe has affinity for Al. That is, a mold member considerably easily reacts with a molten Al, and an Fe-Al intermetallic compound is produced. Thus, a surface layer of the mold member may come off. This phenomenon is called "melting loss". The melting loss encompasses coming-off caused by adhesion or seizing.

[0004] The melting loss tends to occur to, e.g., a stepped part, or the core pin, of the mold that is located around a projection gate and contacts a high-temperature molten Al flow at a high speed.

[0005] If the melting loss grows, then a product having a

defect may result, or a product may not be easily separated from the mold.

[0006] Thus, there has been a demand for a material of a mold member that is excellent in resistance to Al-melting loss.

[0007] Conventionally, it has been practiced to carry out a surface treatment, such as soft nitriding, so as to modify a surface layer of a mold member into a modified layer having a higher resistance to Al-melting loss than that of the base metal.

[0008] However, even if the surface layer of the mold member may be modified by the surface treatment, the melting loss of the mold member is just prevented during an initial period in which the modified layer remains in the surface of the mold member. As time elapses, the modified layer disappears little by little. Thus, thereafter, the melting loss may occur to the base metal, and the above-indicated problems may arise.

[0009] That is, even if the surface layer of the mold member may be modified by the surface treatment, the base metal of the mold member is strongly required to have an excellent resistance to Al-melting loss.

DISCLOSURE OF THE INVENTION

[0010] It is therefore an object of the present invention to provide a hot work tool steel and a mold member each of which enjoys an excellent resistance to Al-melting loss while retaining excellent toughness and resistance to heat check.

[0011] Thus, claim 1 relates to a hot work tool steel characterized by having a composition in wt %: C: 0.10 % to

0.35 %, Si: less than 0.80 %, Mn: 3.0 % or less, Cr: 2.0 % or more and less than 7.0 %, 1/2W + Mo: 0.3 % to 5.0 %, N: more than 0.05 % and 0.50 % or less, C + N: 0.20 % to 0.60 % (with a proviso that C/N: 6 or less), O: 0.0100 % or less, P: 0.050 % or less, Al: 0.050 % or less, and the balance: substantially Fe.

[0012] Claim 2, dependent from claim 1, is characterized by further containing, in wt %, V: 0.01 % or more and less than 0.5 %.

[0013] Claim 3, dependent from claim 1 or claim 2, is characterized by further containing at least one of Ni: 2.0 % or less and Co: 5.0 % or less.

[0014] Claim 4, dependent from any of claims 1 through 3, is characterized by further containing at least one of Ti: 1.0 % or less, Ta: 1.0 % or less, B: 0.010 % or less, and Cu: 1.0 % or less.

[0015] Claim 5, dependent from any of claims 1 through 4, is characterized by further containing at least one of S: 0.050 % or less, Ca: 0.0100 % or less, Se: 0.0100 % or less, Te: 0.0100 % or less, Zr: 0.0100 % or less, Mg: 0.0100 % or less, and Y: 0.100 % or less.

[0016] Claim 6 relates to a mold member characterized by being formed of the hot work tool steel according to any of claims 1 through 5.

[0017] Claim 7 also relates to a mold member characterized by being formed of the hot work tool steel according to any of claims 1 through 5 and having a surface layer which is modified, by a surface treatment, into a layer having a higher resistance to Al-melting loss than that of a base metal.

[0018] The Inventors carried out extensive studies on a hot work tool steel with respect to its resistance to Al-melting loss, and found that the resistance to Al-melting loss is improved by increasing the amount of N.

[0019] Additionally, the Inventors found that if the N amount is just increased, then coarse grains of primary carbonitride are formed when the amount of V is large and accordingly the mold member may not enjoy necessary toughness or heat-check resistance, and that lowering of the properties of the mold member such as toughness or heat-check resistance can be prevented by decreasing the V amount and, in addition, controlling the sum of respective amounts of C and N and the ratio of C amount to N amount (i.e., C/N), to respective appropriate ranges.

[0020] The present invention has been developed based on the above-indicated findings, and consists in increasing the N amount, decreasing the V amount, and controlling the total amount C+N and the ratio C/N to the respective appropriate ranges. The hot work tool steel in accordance with the present invention can enjoy a high resistance to Al-melting loss without lowering its toughness or resistance to heat check.

[0021] A conventional hot work tool steel contains V as an essential component.

[0022] For example, JIS SKD61 contains V: 0.8 % to 1.20 %; JIS SKD62 contains V: 0.20 % to 0.60 %; and JIS SKD8 contains V: 1.70 % to 2.20 %.

[0023] In those conventional hot work tool steels, V works

such that vanadium carbide increases hardness and wear resistance. In addition, fine secondary vanadium carbide refines, owing to so-called "pinning effect", crystal grains of each steel and thereby contribute to improving toughness thereof.

[0024] However, coarse primary vanadium carbide that is produced when each steel is solidified may adversely influence, i.e., lower toughness or heat-check resistance of the each steel.

[0025] In contrast, the invention hot work tool steel containing the increased amount of N may not contain V that has been thought as an essential component for the conventional hot work tool steels. In this case, too, the invention steel can enjoy sufficiently high toughness and heat-check resistance.

[0026] The reasons for the above-indicated properties of the invention hot work tool steel have not been elucidated yet. However, it is speculated that the increased amount of N reacts with, e.g., Cr to form fine nitride, which in turn replaces fine secondary vanadium carbide and thereby refines crystal grains of the steel and improve the toughness and heat-check resistance of the steel.

[0027] If the invention hot work tool steel does not contain V, then the invention steel is freed of the adverse influences of the coarse primary vanadium carbide, and accordingly can enjoy improved toughness and heat-check resistance.

[0028] However, V works to increase hardness and wear resistance. Therefore, in a particular case where it is required to increase toughness and heat-check resistance rather than hardness and wear resistance, it is possible that the invention

steel may not contain V; and in a particular case where it is required to increase hardness and wear resistance rather than toughness and heat-check resistance, it is possible that the invention steel may contain a small amount of V that is not more than an appropriate amount. That is, it is possible to select an appropriate one of the two manners depending upon the requirements.

[0029] However, in the case where the invention steel contains V, it is needed to limit the content of V to a small amount less than 0.5 %.

[0030] In the case where the invention hot work tool steel is used to form a mold member for die-casting, a cycle time of repairing of the mold member can be increased irrespective of whether a surface layer of the mold member may be modified by a surface treatment. Thus, the accuracy of dimensions of products can be kept at a high degree for a long time.

[0031] In addition, the surface treatment to modify the surface layer of the mold member can be omitted, which leads to reducing the cost needed for the mold member.

[0032] Since the surface treatment can be omitted, it is possible to save work that would otherwise be needed to repeat the surface treatment each time the mold member is repaired. In addition, the frequency of repairing of the mold member can be decreased. Thus, the cost needed to repair the mold member can be reduced.

[0033] However, according to claim 7 of the present invention, the surface layer of the mold member may be modified

by a surface treatment into a modified layer having a higher resistance to Al-melting loss than that of the base metal.

[0034] Thus, the surface treatment to modify the surface layer of the mold member can further increase the melting-loss resistance thereof.

[0035] Examples of the surface treatment to modify the surface layer of the mold member are as follows:

1. Diffusion Method

(A) Nitriding

Salt bath nitriding	Nitrosulphurizing
Gas nitriding	Soft nitriding
Plasma nitriding	Hard nitriding

2. Coating Method

(A) CVD

Thermal CVD (e.g., a single layer or multiple layers of a compound such as TiN, TiC, TiCN, or Al_2O_3 is or are formed)

Plasma CVD (e.g., a single layer or multiple layers of a compound such as TiN, TiAlN, TiC, TiCN, or DLC is or are formed)

(B) PVD

Ion plating (e.g., a single layer or multiple layers of a compound such as TiN, TiAlN, CrN, TiC, TiCN, or DLC is or are formed)

Sputtering (e.g., a single layer or multiple layers of a compound such as TiN, TiAlN, CrN, or Al_2O_3 is or are formed)

(C) Oxidization (e.g., a single layer or multiple layers of a compound such as Fe_2O_3 or Fe_3O_4 is or are formed)

[0036] Hereinafter, reasons for respective limits of respective chemical components of the invention steel will be described in detail.

[0037] C: 0.10 % to 0.35 %

C is an element needed to obtain sufficient hardness and wear resistance. In order that the invention hot work tool steel may have sufficient hardness and wear resistance, the invention steel is needed to contain not less than 0.10 % of C.

[0038] However, if the content of C is excessive, then coarse eutectic carbide is produced when an ingot steel is formed, and an amount of carbide that is not solved upon quenching increases and accordingly toughness and wear resistance lower. Therefore, the upper limit of the C content is selected at 0.35 %.

[0039] Si: < 0.80 %

Si is needed as a deoxidizing element. In addition, Si is effective to increase machinability and resistance to quenching softening.

[0040] However, if the content of Si is excessive, then toughness and heat-check resistance lower. Therefore, the upper limit of the Si content is selected at less than 0.80 %. Preferably, the Si content is more than 0.10 % and 0.50 % or less.

[0041] Mn: ≦3.0 %

Mn is needed as a deoxidizing element, and is also needed to obtain sufficient quenchability and hardness. Preferably, the Mn content is not less than 0.02 %. More preferably, the Mn content is not less than 0.1 % and, still more preferably, the Mn content is not less than 0.3 %.

[0042] However, if the Mn content is excessive, then workability lowers. Hence, the upper limit of the Mn content is selected at not more than 3.0 %, more preferably, not more than 2.0 %, still more preferably, not less than 1.0 %.

[0043] Cr: 2.0 % or more and less than 7.0 %

Cr is needed to form carbide and thereby strengthen the base metal and improve the wear resistance thereof, and is also needed to obtain sufficient quenchability. Thus, the Cr content is not less than 2.0 %. More preferably, the Cr content is not less than 3.0 % and, still more preferably, the Cr content is not less than 4.0 %.

[0044] However, if the Cr content is excessive, then quenchability and hot strength lower. Hence, the upper limit of the Cr content is selected at less than 7.0 %, more preferably, not more than 6.5 %.

[0045] 1/2W + Mo: 0.3 % to 5.0 %

W and Mo are needed to form carbides and thereby strengthen the base metal and improve the wear resistance thereof, and are also needed to obtain sufficient quenchability. To this end, the total content of W and Mo is not less than 0.3 %.

[0046] However, if the total content of W and Mo is excessive, then toughness lowers. Hence, the upper limit of the total content of W and Mo is selected at 5.0 %.

[0047] Mo and W are equivalent to each other, and the atomic weight of W is about twice that of Mo. Hence, as far as the present invention is concerned, the total content of W and Mo is defined by Mo equivalent. The invention steel may contain either

one, or both, of W and Mo.

[0048] N: more than 0.05 % and 0.50 % or less

N is an element needed to increase resistance to Al-melting loss, and hardness. It is speculated that the improvement of the resistance to Al-melting loss may result from the production of fine nitride and fine carbonitride. To this end, the N content is more than 0.05 %.

[0049] However, if the N content is excessive, then an amount of coarse eutectic carbonitride increases and accordingly toughness and resistance to heat check lower. In addition, the N content has an upper limit corresponding to a specific alloy composition. Thus, the upper limit of the N content is selected at 0.50 %.

[0050] C + N: 0.20 % to 0.60 %

It is needed to limit the total amount of C and N to not more than 0.60 %, so as to restrain the formation of eutectic carbonitride and thereby improve toughness.

[0051] However, if the total amount of C and N is insufficient, then hardness lowers. Therefore, the lower limit of the total amount of C and N is selected at 0.20 %. Preferably, the total amount of C and N ranges from 0.30 % to 0.45 %.

[0052] C/N: ≦6

The Inventors have found that resistance to Al-melting loss can be effectively improved by adding N and reducing the amount of C, i.e., can be largely improved by controlling the ratio of C amount to N amount, i.e., C/N to not more than 6. It is speculated that the reason for this property

may be such that the amounts of fine nitride and fine carbonitride increase.

[0053] O: ≦0.0100 %

O is an element whose amount should be reduced, because it lowers toughness and resistance to heat check. However, O is an element that is inevitably contained. Hence, according to the present invention, O is limited to not more than 0.0100 %, preferably, not more than 0.0030 %.

[0054] P: ≦0.050 %

P is an element whose amount should be reduced, because it lowers toughness and resistance to heat check. However, P is an element that is inevitably contained. Hence, according to the present invention, P is limited to not more than 0.050 %, preferably, not more than 0.015 %.

[0055] Al: ≦0.050 %

Al is an element effective as a strong deoxidizer. In addition, Al is effective to prevent coarsening of crystal grains and improve nitridability. Preferably, the Al content is not less than 0.001 %.

[0056] However, if the Al content is excessive, then cleanliness or machinability of the steel lowers. Therefore, the Al content is limited to not more than 0.050 %.

[0057] V: 0.01 % or more and less than 0.5 %

V is effective to form carbide and thereby strengthen the base metal and improve the wear resistance thereof, and is also effective to form fine carbide and thereby refine the crystal grains of the steel and increase the toughness thereof. Thus, the

invention steel may contain not less than 0.01 % of V, as needed.

[0058] However, if the V content is excessive, then coarse grains of eutectic carbide or carbonitide are produced when an ingot steel is formed, and amounts of carbide and carbonitide that are not solved upon quenching increase and accordingly toughness and wear resistance lower. Therefore, the V content is limited to less than 0.5 %, preferably, not more than 0.4 %, more preferably, not more than 0.3 %.

[0059] Ni: ≦2.0 %

Ni is effective to increase quenchability and strengthen the base metal, and accordingly can be contained, as needed. Preferably, the amount of Ni is not less than 0.01 %, more preferably, not less than 0.03 %, still more preferably, not less than 0.05 %.

[0060] However, if the Ni content is excessive, then workability lowers. Thus, the upper limit of the Ni content is selected at 2.0 %. Preferably, the Ni content is not more than 1.5 %, more preferably, not more than 1.0 %.

[0061] Co: ≦5.0 %

Co is effective to strengthen the base metal and improve wear resistance, and accordingly can be contained, as needed. Preferably, the amount of Co is not less than 0.01 %, more preferably, not less than 0.03 %, still more preferably, not less than 0.05 %.

[0062] However, if the Co content is excessive, then workability lowers. Thus, the upper limit of the Co content is selected at 5.0 %. Preferably, the Co content is not more than

4.0 %, more preferably, not more than 3.0 %.

[0063] Ti: ≦1.0 %

Ti is effective to form carbonitride and thereby prevent coarsening of crystal grains when the invention steel is quenched, and accordingly can be contained, as needed. Preferably, the amount of Ti is not less than 0.01 %, more preferably, not less than 0.03 %, still more preferably, not less than 0.05 %.

[0064] However, if the Ti content is excessive, then coarse carbonitride grains are formed, and accordingly toughness and resistance to heat check lower. Thus, the upper limit of the Ti content is selected at 1.0 %. Preferably, the Ti content is not more than 0.7 %, more preferably, not more than 0.5 %.

[0065] Ta: ≦1.0 %

Ta is effective to form carbonitride and thereby prevent coarsening of crystal grains when the invention steel is quenched, and accordingly can be contained, as needed. Preferably, the amount of Ta is not less than 0.01 %, more preferably, not less than 0.03 %, still more preferably, not less than 0.05 %.

[0066] However, if the Ti content is excessive, then coarse carbonitride is formed, and accordingly toughness and resistance to heat check lower. Thus, the upper limit of the Ta content is selected at 1.0 %. Preferably, the Ta content is not more than 0.7 %, more preferably, not more than 0.5 %.

[0067] B: ≦0.010 %

B is an element effective to improve quenchability,

and accordingly can be contained, as needed. Preferably, the amount of B is not less than 0.0001 %, more preferably, not less than 0.0003 %, still more preferably, not less than 0.0005 %.

[0068] However, if the B content is excessive, then hot workability and toughness lower. Thus, the upper limit of the B content is selected at 0.010 %. Preferably, the B content is not more than 0.007 %, more preferably, not more than 0.005 %.

[0069] Cu: ≦1.0 %

Cu is effective to strengthen the base metal, and accordingly can be contained, as needed. Preferably, the amount of Cu is not less than 0.01 %, more preferably, not less than 0.03 %, still more preferably, not less than 0.05 %.

[0070] However, if the Cu content is excessive, then toughness lowers. Thus, the upper limit of the Cu content is selected at 1.0 %. Preferably, the Cu content is not more than 0.7 %, more preferably, not more than 0.5 %.

[0071] S: ≦0.050 %

S is an inevitably contained element. Since, however, S is effective to improve machinability, it can be added, as needed. However, if the S content is excessive, then toughness lowers. Thus, the upper limit of the S content is selected at 0.050 %.

[0072] Ca: ≦0.0100 %

Ca is an element effective to improve machinability, and accordingly can be contained, as needed. However, if the Ca content is excessive, then toughness lowers. Thus, the upper limit of the Ca content is selected at 0.0100 %.

[0073] Se: ≦0.0100 %

Se is an element effective to improve machinability, and accordingly can be contained, as needed. However, if the Se content is excessive, then toughness lowers. Thus, the upper limit of the Se content is selected at 0.0100 %.

[0074] Te: ≦0.0100 %

Te is an element effective to improve machinability, and accordingly can be contained, as needed. However, if the Te content is excessive, then hot workability lowers. Thus, the upper limit of the Te content is selected at 0.0100 %.

[0075] Zr: ≦0.0100 %

Zr is an element effective to improve machinability, and accordingly can be contained, as needed. However, if the Zr content is excessive, then toughness lowers. Thus, the upper limit of the Zr content is selected at 0.0100 %.

[0076] Mg: ≦0.0100 %

Mg operates as a deoxidizing and desulfuring element when an ingot steel is produced. In addition, Mg is effective to improve the strength and ductility of the invention steel at high temperatures.

[0077] Thus, Mg can be contained, as needed. However, if the Mg content is excessive, then hot workability lowers. Thus, the upper limit of the Mg content is selected at 0.0100 %.

[0078] Y: ≦0.100 %

Y is effective to form an oxide film on an outer surface of the mold member and thereby improve the wear resistance, seizure resistance, and heat-check resistance thereof, and accordingly it can be contained, as needed. However, if the Y

content is excessive, then toughness lowers. Thus, the upper limit of the Y content is selected at 0.100 %.

BEST MODE FOR CARRYING OUT THE INVENTION

[0079] Hereinafter, embodiments of the present invention will be described in detail.

[0080] <Embodiment 1>

50 kg of each steel having a corresponding composition shown in TABLE 1 is molten in a compressing and melting furnace that can compress, for the purpose of increasing a concentration of nitrogen in a steel ingot, a gas in a melting and casting device as a whole, up to 10 atmospheres, and the molten steel is cast. However, regarding conventional steels shown in TABLE 1, 50 kg of each conventional steel is molten in a vacuum melting furnace, and the molten steel is cast.

[0081]

TABLE 1 CHEMICAL COMPOSITION

		C	Si	Mn	Cr	Mo	W	1/2W+Mo	V	O	N	C+N	C/N	Cu	Ni	Co	Al	P	S	Fe	OTHERS
INVENTION EXAMPLES	1	0.25	0.12	0.63	5.21	2.03	-	2.03	0.05	0.0012	0.152	0.402	1.64	-	-	-	0.026	0.013	0.007	Bal.	
	2	0.22	0.14	0.81	5.64	1.52	-	1.52	0.03	0.0025	0.202	0.422	1.09	-	-	-	0.016	0.012	0.015	〃	
	3	0.31	0.17	0.62	5.43	2.98	-	2.98	-	0.0018	0.283	0.593	1.10	-	-	-	0.021	0.014	0.006	〃	
	4	0.14	0.24	0.78	4.97	2.03	-	2.03	0.09	0.0022	0.221	0.361	0.63	-	-	-	0.034	0.009	0.008	〃	
	5	0.22	0.05	0.63	5.52	3.04	-	3.04	-	0.0017	0.157	0.377	1.40	-	-	-	0.028	0.015	0.007	〃	
	6	0.34	0.16	0.58	3.04	2.47	-	2.47	0.12	0.0014	0.183	0.523	1.86	-	-	-	0.008	0.049	0.006	〃	
	7	0.11	0.08	0.75	5.89	1.97	-	1.97	0.09	0.0006	0.098	0.208	1.12	-	0.84	-	0.014	0.011	0.006	〃	
	8	0.17	0.26	0.59	6.03	1.24	-	1.24	0.11	0.001	0.173	0.343	0.98	-	-	-	0.048	0.013	0.007	〃	Ca:0.0051%
	9	0.23	0.28	0.84	6.54	0.38	-	0.38	0.25	0.0021	0.185	0.415	1.24	-	1.24	-	0.034	0.014	0.003	〃	
	10	0.20	0.14	0.71	5.31	2.82	-	2.82	0.31	0.0013	0.171	0.371	1.17	-	-	-	0.022	0.015	0.004	〃	
	11	0.28	0.32	0.69	4.58	2.23	-	2.23	0.48	0.0017	0.237	0.517	1.18	0.62	-	-	0.018	0.012	0.007	〃	
	12	0.11	0.05	2.53	3.52	4.98	-	4.98	0.39	0.0013	0.487	0.597	0.23	-	-	-	0.004	0.003	0.001	〃	
	13	0.34	0.78	1.25	5.34	2.91	-	2.91	-	0.0009	0.058	0.398	5.86	-	0.74	-	0.028	0.019	0.009	〃	
	14	0.21	0.08	2.91	6.76	2.35	-	2.35	0.07	0.0093	0.313	0.523	0.67	-	-	-	0.019	0.015	0.012	〃	
	15	0.11	0.07	0.58	6.52	0.85	4.81	3.26	0.46	0.0014	0.187	0.297	0.59	-	-	1.24	0.031	0.014	0.044	〃	Ca:0.0082% Zr:0.0061%
	16	0.34	0.34	0.61	6.13	0.33	-	0.33	0.38	0.0013	0.224	0.564	1.52	-	-	2.97	0.018	0.013	0.021	〃	B:0.008%
	17	0.28	0.29	0.92	5.46	3.48	0.62	3.79	0.18	0.0017	0.312	0.592	0.90	-	-	-	0.004	0.01	0.048	〃	
	18	0.21	0.15	0.73	5.53	2.08	1.52	2.84	0.23	0.0016	0.291	0.501	0.72	-	-	-	0.023	0.015	0.025	〃	Ti:0.76% Ta:0.81%
	19	0.33	0.24	0.58	6.92	1.98	-	1.98	0.14	0.0023	0.143	0.473	2.31	-	-	4.98	0.021	0.012	0.043	〃	Se:0.0065% Te:0.0041%
	20	0.26	0.19	0.61	6.24	2.76	-	2.76	0.35	0.0014	0.162	0.422	1.60	-	-	-	0.033	0.013	0.008	〃	Mg:0.0068% Y:0.082%
COMPARATIVE STEELS	21	0.41	0.15	0.63	5.52	3.04	-	3.04	1.03	0.0017	0.007	0.417	58.57	-	-	-	0.028	0.015	0.007	〃	
	22	0.42	0.16	0.59	5.45	2.98	-	2.98	1.01	0.016	0.185	0.605	2.27	-	-	-	0.019	0.014	0.005	〃	
	23	0.32	0.14	0.67	5.57	2.97	-	2.97	0.98	0.018	0.183	0.503	1.75	-	-	-	0.025	0.013	0.007	〃	
	24	0.07	0.17	0.71	5.48	3.01	-	3.01	0.97	0.012	0.181	0.188	0.39	-	-	-	0.027	0.016	0.008	〃	
	25	0.45	0.16	0.64	5.51	2.98	-	2.98	0.31	0.019	0.182	0.632	2.47	-	-	-	0.016	0.014	0.006	〃	
	26	0.29	1.26	0.68	5.56	3.03	-	3.03	0.27	0.021	0.178	0.468	1.63	-	-	-	0.018	0.013	0.005	〃	
*	27	0.38	1.02	0.42	5.12	1.23	-	1.23	1.06	0.0015	0.009	0.389	42.22	-	-	-	0.019	0.015	0.007	〃	JIS SKD61
	28	0.38	0.85	0.41	4.96	1.21	1.36	1.89	0.44	0.0018	0.005	0.385	76.0	-	-	-	0.022	0.011	0.006	〃	JIS SKD62
	29	0.40	0.42	0.49	4.35	0.41	4.24	2.53	2.03	0.0012	0.007	0.407	57.14	-	-	4.03	0.024	0.016	0.007	〃	JIS SKD8

* : CONVENTIONAL STEELS

[0082] Subsequently, soaking is carried out under a condition of 1,230 °C x 10 hr, and each steel is forged into 60-mm square rods, which in turn are annealed under a condition of 870 °C x 3 hr followed by slow cooling. Then, test specimens including an Al-melting-loss test specimen, a hardness test specimen, a Charpy impact test specimen, a heat-check test specimen, and a high-temperature Ohgoshi-type wear test specimen are roughly worked.

[0083] Subsequently, quenching and tempering are carried out under conditions shown in TABLE 2 (however, regarding the hardness test specimens, quenching and tempering are carried out under a condition (B), described later). Then, the Al-melting-loss test specimen, the hardness test specimen, the Charpy test specimen, the heat-check test specimen, and the high-temperature Ohgoshi-type wear test specimen are precisely worked.

[0084] The Al-melting loss test specimen is worked to have dimensions of ϕ 10 mm x 60 mmL; the hardness test specimen is worked to have dimensions of 10 mm square x 10 mm; the Charpy impact test specimen is worked into a JIS No. 3 test specimen; the heat-check test specimen is worked to have dimensions of ϕ 15 mm x 5 mm; and the high-temperature Ohgoshi-type wear test specimen is worked to have dimensions of 10 mm x 17 mm x 30 mm.

[0085]

TABLE 2

SORTS OF STEELS	QUENCHING	TEMPERING	HARDNESS
SKD61 (No. 27), SKD62 (No. 28)	1030℃×30min→OIL COOLING	620～630℃×1h→AIR COOLING, TWICE	HRC45
STEELS Nos. 1 TO 14 & 20 TO 26	1030℃×30min→OIL COOLING	600～670℃×1h→AIR COOLING, TWICE	HRC45
SKD8 (No. 29)	1175℃×30min→OIL COOLING	670℃×1h→AIR COOLING, TWICE	HRC45
STEELS Nos. 15 TO 19	1175℃×30min→OIL COOLING	660～680℃×1h→AIR COOLING, TWICE	HRC45

[0086] Each of the test specimens is subjected to a corresponding one of an Al-melting-loss test, a hardness test, a Charpy impact test, and a heat-check test under a corresponding one of the following conditions (A) through (E).

[0087] The obtained results are shown in TABLE 3.

[0088] (A) Al-Melting-Loss Test

A 30-mm portion of the test specimen is dipped in a molten bath of Al, and is rotated such that a center of the test specimen describes a circle having a diameter of 30 mm. Then, loss of the test specimen caused by melting with Al is inspected.

- Al alloy : B390 (Al-17Si-4.5Cu)
- temperature of molten bath : 750 °C
- rotation speed : 200 rpm
- dipping time : 30 minutes

[0089] After the test, the test specimen is dipped in a saturated aqueous solution of NaOH, so as to remove the Al alloy adhered to the test specimen, and then a weight of the test specimen is measured. A melting-loss resistance of the test specimen is evaluated as a melting-loss percentage that is calculated by the following expression:

Melting-Loss Proportion (%) = (Weight Before Test . ▯ Weight After Test) ÷ (Weight of ϕ 10 mm x 30 mmL Portion Before Test) x 100

[0090] (B) Quench-And-Temper Hardness

In a salt furnace, the test specimen is subjected to a heat treatment under the following conditions, and a Rockwell hardness of the test specimen is measured.

・Quenching : 1,030 °C x 30 minutes, Oil cooling

・Tempering : 650 °C x 1 hour, Air cooling x Twice

[0091] (C) Charpy impact Test

The test specimen is obtained from a widthwise direction of the steel (T direction), and a Charpy impact value of the test specimen is evaluated according to JIS Z 2242.

[0092] (D) Heat-Check Test

The test specimen is evaluated using a high-frequency-heating and water-cooling heat-check test machine. More specifically described, a surface layer of the test specimen is heated up to 700 °C and then is cooled by water, and the heating and the cooling are repeated 1,000 times. Respective depths, and a total number, of crack(s) occurring to the surface layer of the test specimen are measured, and a heat-check resistance of the test specimen is evaluated by an average crack length.

[0093] (E) High-Temperature Ohgoshi-type Wear Test

An Ohgoshi-type wear test at 700 °C is carried out, and respective results obtained from the test specimens are indicated by respective index values each of which is calculated under a condition that a result, i.e., a wear resistance obtained from the test specimen of conventional steel No. 27 is defined as 100.

[0094]

TABLE 3

	No.	MELTING-LOSS PERCENTAGE (%)	650℃-TEMPERING HARDNESS (HRC)	CHARPY IMPACT VALUE (J/cm2)	AVERAGE CRACK LENGTH (μm)	WEAR RESISTANCE	REMARKS
INVENTION EXAMPLES	1	18	42.3	46	17	105	
	2	15	41.7	44	16	107	
	3	12	43.4	48	19	102	
	4	19	40.7	42	17	103	
	5	16	41.9	47	13	102	
	6	17	43.7	31	19	108	
	7	19	40.3	47	16	103	
	8	18	41.2	43	12	104	
	9	19	42.4	46	18	102	
	10	17	41.5	42	11	106	
	11	16	43.8	34	13	114	
	12	12	43.2	37	17	108	
	13	19	41.3	48	14	103	
	14	13	43.6	43	18	103	
	15	14	40.9	36	16	116	
	16	12	43.8	35	17	113	
	17	13	44.3	37	19	102	
	18	17	43.5	41	17	110	
	19	12	42.4	32	18	107	
	20	16	42.1	34	17	112	
COMPARATIVE STEELS	21	32	44.2	36	11	122	
	22	18	44.8	17	14	128	
	23	28	44.1	33	16	121	
	24	37	41.3	46	22	117	
	25	17	43.9	25	23	104	
	26	22	43.7	12	39	102	
*	27	57	43.3	28	25	100	JIS SKD61
	28	38	45.1	36	42	108	JIS SKD62
	29	41	46.7	26	32	124	JIS SKD8

* : CONVENTIONAL STEELS

[0095] As can be understood from the results shown in TABLE 3, each of conventional steels Nos. 27, 28, and 29 shows a poor melting-loss resistance (melting-loss percentage) and insufficient toughness (Charpy impact value) and heat-check resistance (average crack length).

[0096] In addition, each of comparative steels Nos. 21, 23, and 24 shows a poor melting-loss resistance (melting-loss percentage); each of comparative steels Nos. 22, 25, and 26 shows a low toughness (Charpy impact value); and each of comparative steels Nos. 24, 25, and 26 shows an insufficient heat-check resistance (average crack length). In contrast, each of invention examples shows excellent properties with respect to all of the melting-loss resistance, the hardness, the toughness, the heat-check resistance, and the wear resistance. Above all, each of invention examples Nos. 3, 12, 14, and 17 each of which contains a large amount of N is highly excellent with respect to the melting-loss resistance.

[0097] In addition, each of invention examples Nos. 3, 5, and 13 each of which does not contain V enjoys a high toughness (Charpy impact value).

[0098] <Embodiment 2>

A 50 kg ingot of each steel (an invention example and a conventional steel) having a corresponding composition shown in TABLE 4 is produced in a corresponding one of the same compressing and melting furnace (the invention example) and the same vacuum induction furnace (the conventional steel) each as used in Embodiment 1, and is forged into ϕ20-mm rods, which in

turn are annealed at 870 °C.

[0099]

TABLE 4 CHEMICAL COMPOSITION

SORT	C	Si	Mn	P	S	Cr	Mo	V	Al	O	N	C+N	C/N	REMARKS
CONVENTIONAL STEEL	0. 38	0. 94	0. 56	0. 007	0. 003	5. 43	1. 23	0. 81	0. 009	0. 0016	0. 016	0. 396	23. 75	SKD61
INVENTION EXAMPLE	0. 26	0. 15	0. 62	0. 009	0. 002	5. 51	2. 03	0. 05	0. 008	0. 0013	0. 157	0. 417	1. 66	—

[0100] Subsequently, regarding each of the invention example and the conventional steel, the each steel is cut into three pieces each having a 200-mm length, and each of the three pieces is roughed, by lathe turning, so as to have dimensions of ϕ15 mm x 200 mm. Then, after the three pieces are quenched under a condition of 1,030 °C x 1 hr, those pieces are tempered, twice, under a condition of 580 °C to 590 °C x 8 hr, so that the three pieces have respective hardness values of HRC 38, 45, and 52, respectively.

[0101] Subsequently, each of the three pieces is finished to have a shape of a core-pin, which in turn is subjected to a surface treatment so as to modify a surface layer of the each piece.

[0102] Regarding the surface treatment, the HRC38 piece of each of the invention example and the conventional steel is subjected to gas soft nitriding under a condition of 525 °C x 2.5 hr; and the HRC52 piece of each of the invention example and the conventional steel is subjected to PVD method so as to form a CrN film.

[0103] No surface treatment is carried out on the HRC45 piece of each of the invention example and the conventional steel.

[0104] A casting test is carried out using an Al-die-casting mold (cylinder-head type) assembled with the above-indicated core-pin. The core-pins that have not been subjected to the surface treatment are used up to 5,000 casting shots; and the core-pins that have been subjected to the surface treatment are used up to 20,000 casting shots.

[0105] Respective weights of the core-pins before and after

the casting are measured.

[0106] More specifically described, each core-pin after the casting is dipped in a saturated aqueous solution of NaOH, so as to remove the Al alloy adhered to the each pin, and then a weight of the each pin is measured.

[0107] An amount of each core-pin that is decreased by melting loss is obtained according to the following expression: (Weight Before Test) − (Weight After Test), and a melting loss of the each pin is evaluated.

[0108] TABLE 5 shows the thus obtained results.

[0109]

TABLE 5

SORT	MELTING-LOSS DECREASE AMOUNT		
	NO SURFACE TREATMENT	GAS SOFT NITRIDING	PVD METHOD
CONVENTIONAL STEEL	3.6g	2.73g	0.07g
INVENTION EXAMPLE	1.7g	0.64g	0.03g

[0110] From the results shown in TABLE 5, it can be understood that since, regarding the invention example, the surface layer is modified by the surface treatment, the melting-loss decrease amount is more effectively reduced.

[0111] While the present invention has been detailed in its embodiments, it is to be understood that the present invention is by no means limited to the details of those embodiments but may be embodied with various changes without departing from the

spirit of the invention.